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SOME EFFECTS OF FERTILIZERS ON YIELD,
CHEMICAL COMPOSITION, AND NUTRITIVE VALUE OF FORAGES

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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by

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ABSTRACT

This investigation was conducted to determine the effects of the application of fertilizers on the yield, chemical composition, and nutritive value of some Alberta grown forages. The nutritive value was assessed by feeding experiments with rabbits and sheep.

Four field experiments were selected from 39 field forage fertilizer experiments on the basis of marked yield increases from fertilization and botanical purity. The data for chemical analysis of the forage revealed a consistent increase in nitrogen and potassium content of fertilized forage as compared to unfertilized forage. Other mineral constituents were not increased or decreased consistently by the application of fertilizers.

Harvesting and curing difficulties resulted in some deterioration of two sets of forages before they were used for feeding experiments. However, the results from the other two feeding experiments showed that rabbits fed fertilized forage made faster and more efficient gains than rabbits fed unfertilized forage. Rabbits and sheep consumed more feed and digested more nutrients when fed fertilized forage than when fed unfertilized forage.

An artificial rumen technique was used in an attempt to evaluate forage quality in the laboratory. Volatile fatty acid production and dry matter loss, by this technique, were greater for fertilized forage than for unfertilized forage.

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INTRODUCTION

The production of forages in Alberta has increased as the livestock industry has grown. In the early years the forages were chiefly uncultivated varieties and production depended primarily on the amount of precipitation. As livestock production became more intensive, farmers came to rely more on cultivated forages for their feed supply. At the same time the valuable role that forages can play in conserving the soil and maintaining its productivity was more widely recognized. The recent expansion of urban centres has increased markedly the demand for milk, milk products, and beef. This increased demand has created a need for greater productivity of milkshed pastures, hay lands, and other grazing lands.

Commercial fertilizers have been used in Alberta for 30 years. However, fertilizers have not been applied extensively to forage crops, in spite of numerous data that prove that highly profitable yield increases may result from their use.

In recent years there has been considerable interest in the effect fertilization may have on the nutritive value of forages. Some nutritionists question the need to supply mineral requirements of animals through forages and grains. Animal scientists have demonstrated the practicability of feeding phosphorus, calcium, iodine, and cobalt as mineral supplements. However, it may be true that, when any of these nutrients by-passes the plant, some other nutrients may be by-passed as well. Consider an example involving carotene.

Carotene is a precursor to a vitamin required by all animals --> vitamin A. Usually any soil nutrient deficiency which results in chlorosis of the plant results in a lowered carotene content. In Alberta, where the supply of vitamin A for most livestock during the long winter feeding period is forages, a low vitamin A content in these forages might become a very serious economic problem. Similar relationships probably exist between other mineral deficiencies and other organic compounds of nutritional importance. The occurrence and importance of such relationships cannot be discovered easily by chemical analysis of plants, because of the complexity of the compounds involved. The sufficiency of some of the dietary essentials involved is most easily determined by the health and performance of animals.

In view of the importance of forages to the livestock industry, a study was undertaken to determine whether fertilization of some Alberta grown forage can improve their nutritive value. The results of this study are presented in this report.

LITERATURE REVIEW

A. General Basic Concepts

At least 13 nutrient elements must be available in the soil if normal plant growth is to be obtained (31). These plant nutrients are commonly referred to as essential elements, since the plant cannot complete its life cycle without an adequate supply of them. Plant nutrient elements are sometimes classified on the basis of their function or role in plants. One such grouping follows: nutrients associated with plant storage of energy, namely nitrogen, sulfur, and phosphorus; nutrients concerned with translocation of substances within the plant, namely potassium, calcium, and magnesium; and elements having to do with oxidation and reduction processes within the plant, namely manganese, iron, and copper (55). The most common classification of plant nutrients is based on their subdivision into two categories dependent on the quantities occurring in plants. Essential plant nutrients present in very small quantities are classified as micro-nutrients and are listed as iron, manganese, zinc, copper, molybdenum, boron, and chlorine. The other essential nutrients obtained from the soil are termed macro-nutrients and include nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur (31).

The chemical composition of plants may be strongly affected by the nutrient supply in the soil on which the plants grow. The actual quantities of nutrients taken up

from soils are highly variable, because uptake is affected by many factors. Among the factors involved are species, age, and root distribution of the plant, physical and chemical nature of the soil, methods of cultivation, and general climatic conditions (78). However, definite relationships may exist between the supply of nutrients in the soil, the concentration of nutrients in the crop, and the yield of the crop (61). Figure I reproduced from Norman (61) illustrates such relationships. The graph shows that a certain minimum supply of each nutrient is necessary to support plant growth. As the supply in the soil increases yield also increases, but the amount in the plant does not vary much until a certain level in the soil is reached. Beyond this point yield and amounts of nutrients in the plant increase with increasing supply in the soil. This relationship continues until yield is no longer affected by the nutrient supply in the soil at which level the plant enters a stage of luxury consumption. In the stage of luxury consumption the amounts of nutrients in the plant increase, but the yield does not change.

A major concern in soil fertility studies is why some soils are good growth media for plants and why many are poor. These studies also seek methods to improve productivity of poor soils and to conserve the productivity of good soils (72). The application of nutrients to the soil may increase the productivity of that soil. Of the essential nutrients, which plants obtain from the soil, four are most

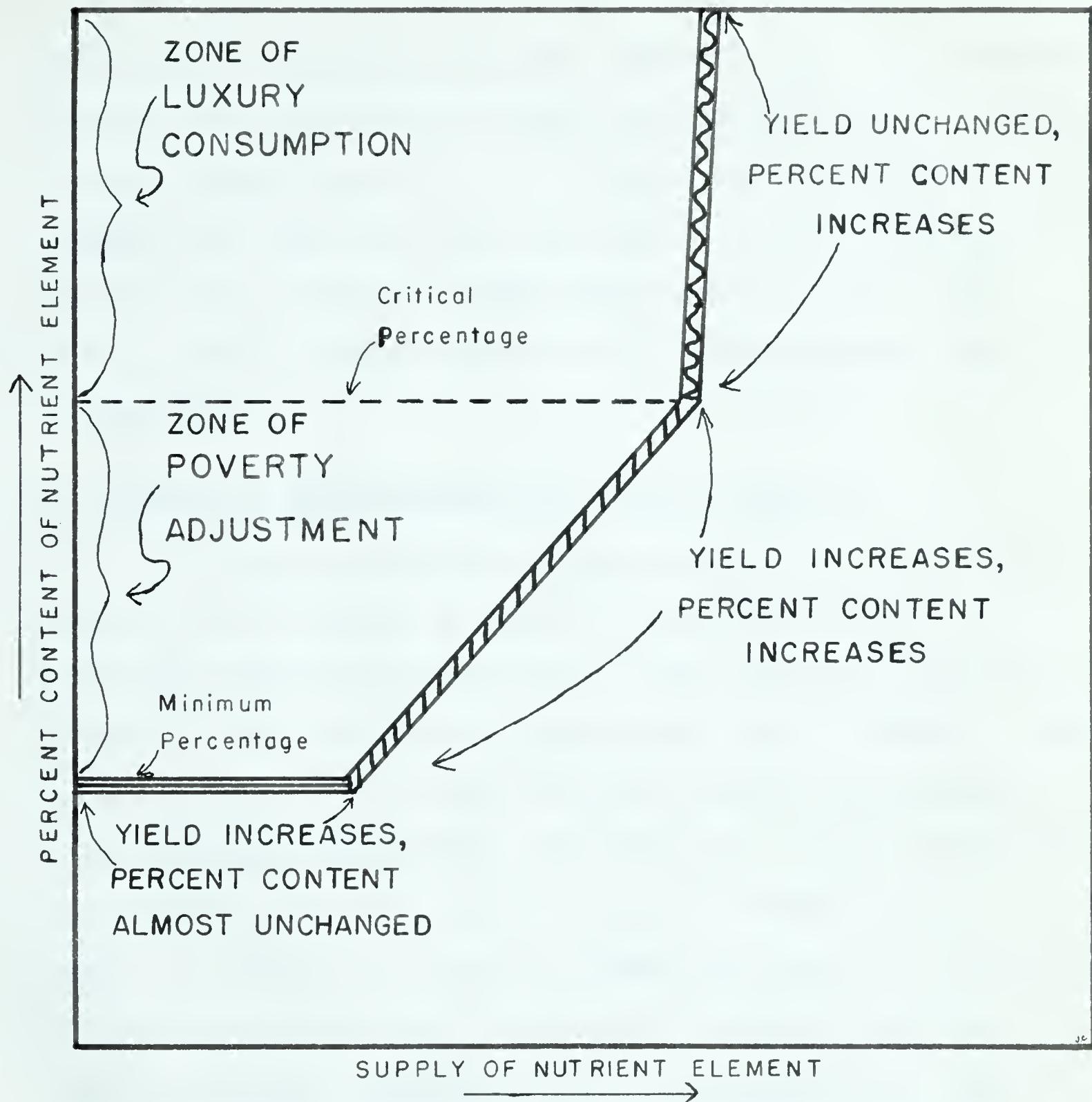


Figure 1. Relationships among supply of nutrient in the soil, concentration of the nutrient in the plant, and yield of the crop (Norman, 61).

likely to be deficient in Alberta soils (5). They are nitrogen, phosphorus, sulfur, and potassium. Iron, manganese, and boron may be deficient in a few Alberta soils. For practical reasons the literature reviewed has been restricted to those nutrients most likely to be deficient for the growth of forage crops under Alberta conditions. In the literature review each nutrient is considered separately as it may affect yield, chemical composition, and biological value of forage crops.

B. Effect of Fertilization on Yield of Forages

Alberta soils vary considerably in their nutrient status. Plants grown on soils in different parts of the province respond to fertilization with different nutrients, because of this variation in available nutrient supply. The greatest responses in terms of plant growth are obtained with nitrogen, phosphorus, and sulfur (5). The results from fertilization also vary with the plant species or mixture of species. Results of fertility experiments must be considered for more than one season because of variations from year to year in rainfall, sunshine, wind, and temperature. Some of the yield effects resulting from fertilization have been striking.

(1) Nitrogen

The effect of nitrogenous fertilizers on the yield of various crops has been studied in great detail. Nitrogen fertilization has been found by many investigators (17, 20, 26,

49, 50, 52, 59) to produce increased yields of forage.

The effective level of nitrogen fertilization varies with soil and geographic location. Burton et al. (17) increased the early growth of coastal Bermuda grass phenomenally with heavy applications of nitrogen fertilizer. These results showed an increase from 290 pounds of dry matter per acre on the check to 2,000 pounds per acre on the plot treated with 200 pounds per acre of nitrogen. Although treatments providing 1,500 pounds per acre of nitrogen resulted in maximum yields, the 200 pounds per acre applications gave the most economical yield of forage. Cooper (26) found that increases of 100 per cent in the yield of native flood meadow hay could be obtained from applications of 200 pounds per acre of either ammonium sulfate or calcium nitrate. Mason and Miltimore (52) reported an increase from 640 to 1,060 pounds per acre of dry matter from the application of 60 pounds per acre of nitrogen.

Some reports indicate that nitrogen fertilization had little effect on the yield of forage crops (23, 25). Others stated that this nutrient depressed the yield or reduced the stand of legume in mixed forages (23, 25, 49, 59).

The response of forages to nitrogen fertilization is dependent to a large extent on the availability of other nutrients in the soil. Carlson and Grunes (20) showed that a greater yield of plant material was obtained when nitrogen and phosphorus were applied together than when either was applied alone.

(2) Phosphorus

Forage crop response to phosphorus fertilization depends to a large extent upon the relative proportion of legume in the forage and the amount of available phosphorus in the soil. Increased forage production from the application of phosphate fertilizer has been observed by many investigators (14, 19, 24, 33, 37, 39, 41, 47, 53, 58, 66, 74, 79, 83).

Hanway et al. (39) found that yield of alfalfa could be substantially increased with broadcast applications of phosphorus. His work also showed that residual effects of phosphorus can be measured two years after application. The work reported by Wakefield et al. (74) demonstrated that legumes respond markedly to phosphate fertilization on phosphorus-deficient soils and that the legume in a grass-legume mixture was maintained to a much greater extent when phosphate was applied. They considered that yearly applications of phosphate fertilizer gave a superior response in terms of plant yield over a 4-year period compared to heavy initial applications. This observation was also supported by Cheany et al. (24). Woodhouse (83) reported substantial yield increases of both alfalfa and lespedeza from phosphorus application. He showed that placement differences associated with phosphate fertilization were short term and that yield differences between broadcast phosphorus and phosphorus mixed with the surface 4 inches of soil became negligible in the second and third years after application.

(3) Sulfur

Sulfur has been found to be a limiting nutrient for forage production in several areas of the world (13, 42, 57, 60, 64, 75, 76, 77).

Walker et al. (77) reported yield increases of the order of 18 fold with the application of 200 pounds of gypsum to sulfur-deficient soils growing clover and grass. Although the yield of grass was also increased, this increase was almost certainly associated with improved growth of the clover and underground transference of nitrogen from the clover crop. Bentley et al. (13) have reported a sixfold increase in alfalfa growth from the application of ammonium sulfate. Walker (75) found that a large number of Alberta soils were deficient in sulfur as shown by increased yield of legume plant material after sulfur fertilization. His survey indicated that sulfur-deficiency followed neither a geographical nor a soil series pattern. Legumes on sulfur-deficient Alberta soils are generally greatly benefited by fertilizers supplying sulfur (60).

(4) Potassium

Crops grown on Alberta soils generally have not responded to potassium fertilization. However, recent evidence has shown that crops grown on some soils do respond to potassium application when high rates of nitrogen and phosphorus are used (3). Workers in other areas have reported increased yield of forage from potassium fertilization (25, 39, 74, 83).

Wakefield et al. (74) stated that a general decline in vigor and subsequent yields of a ladino clover crop resulted over a 4-year period when no potassium was applied. Substantial yield increases were recorded from the addition of potassium. However, the greatest yield response resulted from combined applications of potassium and phosphorus.

C. Effect of Fertilization on Chemical Composition of Forages

The chemical composition of plants is determined by many factors other than the level of soil fertility. These factors may be generally divided into two broad categories --- those which are genetic in nature, and those which are environmental in nature. In order to measure the effect of variation in one factor within these categories, it is necessary to control or at least assess the results of all other factors.

When the supply of available nutrients is altered by addition of fertilizers, the resulting crop may change in chemical composition as a result of one or a combination of factors. The botanical composition of the mixed forage may be altered; the leaf-stem ratio may be changed; or the maturity of the forage may be affected. Often the nutrient balance may be changed to the point that luxury consumption occurs, and forage containing an unusually high proportion of one nutrient may result. Increased yield or production accompanying the addition of a nutrient may result in a lower content of other nutrients as they become limiting to growth.

Thus, the study of plant composition becomes extremely complex and the results of fertilization are often unpredictable. In this section some of the changes in plant chemical composition resulting from the addition of plant nutrients to the soil are discussed.

(1) Nitrogen

The application of moderate to heavy rates of nitrogen fertilizers to forage crops has increased the nitrogen content of forages in many cases (17, 18, 23, 26, 36, 51, 52, 59, 71).

Mason and Miltimore (52) reported that the application of nitrogen fertilizer increased sharply the crude protein content of native bluebunch wheatgrass. Their data showed that 60 pounds per acre of nitrogen increased the crude protein from 3.9 per cent to 6.2 per cent. The nitrogen content of white clover and orchard grass increased during a period of 4 to 6 weeks following application of 100 pounds per acre of nitrogen. The increase became negligible after 6 weeks (23).

Nitrogen applications commonly suppress legume growth in grass-legume mixtures. Cooper (26) found that the crude protein content of a grass-legume mixture was decreased by nitrogen fertilization but the decrease was attributed to a greater proportion of grass in the fertilized plots. Similar results have been reported by Leefe (49), who found that the clover content of a grass-legume mixture was reduced to almost nil by the application of 150 pounds per acre of nitrogen.

In studies with eight different grasses nitrogen fertilization has resulted in increased levels of calcium, phosphorus, and crude protein (50).

(2) Phosphorus

The fertilization of various forages with phosphate fertilizer has resulted in increased phosphorus content of the forage in many instances (12, 14, 19, 24, 39, 41, 47, 53, 58, 66, 79). Kuehler (47) reported an increase in phosphorus content of alfalfa with increasing rates of phosphorus fertilization but found that the phosphorus content decreased with plant maturity. This study further showed that phosphorus treatment had little effect on the concentration of nitrogen or other nutrient elements in alfalfa. The work of Black et al. (14) indicated that the concentration of phosphorus in grass forage was more closely associated with rainfall than with phosphorus fertilization. The application of phosphorus did increase the phosphorus content of the forage when sufficient precipitation occurred. Matrone et al. (53) reported an increase in phosphorus and calcium concentration in soybean forage from the application of phosphorus fertilizer, but the variation in crude protein, ether extract, crude fiber, and nitrogen-free extract could not be associated with the phosphorus treatment. Heinmann et al. (41) showed that crude protein, crude fiber, ash, ether extract, calcium, and phosphorus of alfalfa were all increased by phosphorus fertilization.

A close relationship of clover yield and phosphorus content to temperature was reported by Robinson et al. (66). Their data suggested that higher temperatures may either increase phosphorus availability or increase the rate of its absorption by the plant. Clover crops grown at 50° F. and 80° F. with the same phosphorus treatment had phosphorus contents of 0.066 and 0.190 per cent, respectively.

(3) Sulfur

The sulfur content of forages has been increased frequently by the application of sulfur-containing fertilizers (11, 13, 42, 60, 64, 75, 76, 77). Walker et al. (77) found that nearly all the sulfur in clover was in the organic form; whereas, a large fraction of the sulfur in grass was in the sulfate form. Apparently sulfate is more rapidly synthesised to amino acids and protein in legumes than in grasses. Sulfur extracted with hot ethyl alcohol from the plant was a reliable criterion for determining the need for sulfur fertilization (75). Walker (75) proposed that the critical sulfur levels in the total plant tissues for alfalfa, alsike clover, and red clover were 0.21, 0.07, and 0.08 per cent, respectively. Soils producing legumes with sulfur contents below these critical levels were considered sulfur-deficient. This method of determining sulfur deficiency proved satisfactory for more than 85 per cent of the locations tested.

Variations in the amount of an essential nutrient in the plant may be accompanied by even wider variations in

the content of organic constituents in the plant. Rendig and McComb (64) have found that a lack of elemental sulfur resulted in a greater change in the amide and sugar content than in the sulfur content of alfalfa plants. When the level of available sulfur in the soil is low, the plant contains high levels of amide and low levels of sugar. As the sulfur supply in the soil was increased the amide nitrogen content decreased and sugar content increased. Clover produced on sulfur-deficient soil was higher in sulfur, nitrogen, cystine, and methionine content when sulfur fertilizer was applied (11). Nitrogen content of grasses grown in combination with legumes on sulfur-deficient soils increased from 1.3 to 1.7 per cent when 100 pounds per acre of calcium sulfate were applied (77).

(4) Potassium

The fertilization of forages with potassium has resulted in increased potassium content (16, 39, 48, 68, 74). Heavy applications of potassium have resulted in a decrease in calcium, magnesium, and sodium (74). This may have been due to an imbalance produced by the excessive concentration of potassium in the soil. Hanway et al. (39) reported that heavy applications of potassium resulted in decreased magnesium content of ladino clover, but had little effect on nitrogen, phosphorus, and calcium content.

Doll et al. (33) found that the potassium content of forages was not affected by potassium fertilization. A very comprehensive study of several crops has been conducted

for eight years at Michigan State University (32). The results of this study showed very little differences in plant composition between crops grown on fertilized and unfertilized soils (35). Another report suggests that a completely balanced fertilizer does not appreciably change plant composition (63).

D. Effect of Fertilization on Biological Value of Forages

Matrone et al. (53) in discussing the nutritive value of crops stated: "Just as the content of a mineral element in the soil is not a measure of its availability to the plant, similarly the content of a nutrient in the plant is not a measure of its availability to the animal. The final proof of nutritional value, therefore, is still provided only by some response of the animal."

Some of the animals which have been used to measure the biological value of crops grown on fertilized soils have been guinea pigs, rabbits, sheep, and beef and dairy cattle. The biological measures used to assess the nutritive value have included weight gains, carrying capacity, milk and butterfat production, health, feed consumption, and tissue composition. Minature artificial rumen assays may be of value in the determination of forage quality (9). These authors reported that good correlation existed between volatile fatty acid production and dry matter loss in vitro and dry matter digestibility in vivo.

Of all the mineral deficiencies associated with plant composition, phosphorus deficiency is probably the most widespread. Livestock which are dependent to a large extent upon forage crops for their diet frequently show such signs of phosphorus deficiency as depraved appetite, stiffness, muscular weakness, and loss of weight (38). Serious consequences may occur unless this phosphorus deficiency in the diet of animals is corrected. Morrison (56) states that fertilization of phosphorus-deficient soils not only increased yields of crops but generally produced feeds of normal phosphorus content, thereby preventing injury to stock from a lack of the mineral. In an experiment comparing three methods of supplying phosphorus to range cattle on phosphorus-deficient soils, phosphorus fertilization was superior to feeding bonemeal and to the addition of disodium phosphate to the drinking water (14). The calf crop was greater, the weaning weights of the calves were higher, and the cash returns per acre were superior for the group grazing phosphorus-fertilized pasture. Heinman *et al.* (41) reported that the mature body weight of rabbits was significantly greater for rabbits fed phosphorus-fertilized alfalfa than rabbits fed unfertilized alfalfa. In the same experiment rabbits fed phosphorus-fertilized alfalfa required fewer matings per conception, had greater bone strength, and normal bone structure. Reduced bone strength and abnormal bone structure occurred in rabbits fed unfertilized alfalfa even though the calcium, phosphorus, fat, and ash content of the bones were greater.

Matrone et al. (53) in an extensive study reported that phosphate fertilized soil produced from two to three times more soybean hay than did unfertilized soil. The hay produced on fertilized soil was of greater biological value for sheep and rabbits as indicated by the growth of lambs and the growth and bone formation of rabbits. Lambs fed fertilized and unfertilized hay plus Cerelose gained 17.7 pounds and 12.1 pounds, respectively. Although the addition of dicalcium phosphate to the ration corrected the weight gains, it did not normalize inorganic phosphorus levels in the blood serum. The authors stated that these low levels may have resulted from either phosphorus content or phosphorus availability in the soybean forage. The differences in nutritional quality between phosphorus-fertilized and unfertilized soybean forage exceeded the differences that could be attributed to increased protein and phosphorus content and consumption of the fertilized forage. This statement was based on the results obtained when the fertilized and unfertilized feeds were balanced for phosphorus, protein, and energy.

The productivity of a Bermuda grass-legume mixture as affected by phosphate fertilization was measured by beef cattle production (67). The authors reported that pastures top-dressed annually with 0, 200, and 600 pounds of superphosphate produced 61, 275, and 382 pounds of beef per acre, respectively.

Protein is one of the more important organic constituents of forage because of its nutritional value to livestock. Austenson et al. (10) compared production from a

grass-legume pasture to production from a grass pasture heavily fertilized with nitrogen. They found that dry matter production and milk production per acre were higher on the grass plus nitrogen treatment but the production costs were also higher. Woefel and Poulton (82) compared the nutritive value of timothy hay produced on soils treated with 0, 50, 100, and 200 pounds of nitrogen per acre. Crude protein and digestible protein, as determined by lamb-feeding experiments, were significantly increased with increasing nitrogen applications. However, energy digestibility decreased with increased nitrogen application. In a study of meadow hay fertilized with 90 pounds of nitrogen, Hopkins et al. (43) found that the nitrogen treatment lowered the feeding value of hay for cattle, sheep, and rabbits. Digestibility studies with sheep and feeding trials with rabbits failed to explain the nutritional differences between the nitrogen-fertilized and unfertilized hay.

Wedin et al. (80) used guinea pigs to assay the nutritive value of alfalfa and Ladino clover grown on different soil types with and without fertilization. They concluded that the nutritive value of these forages for guinea pigs was closely correlated with the productivity rating of the soil. As measured by the average daily gains of guinea pigs, forage grown on silt loam was of higher nutritive value than that grown on sand. Although forage yield responses to fertilization were consistent, the response in nutritive value for guinea pigs was extremely varied.

Bentley et al. (13) found that applications of sulfur-containing fertilizers to sulfur-deficient soils growing legumes increased the sulfur and nitrogen content of the crop. Rabbits fed forage from sulfur-fertilized plots made faster and more efficient gains than those fed forage from unfertilized plots. These workers found no significant correlations between the nutrient content of the feeds and the marked differences in their nutritive value as measured by rate and efficiency of rabbit gain. Rendig and Weir (65) have evaluated alfalfa grown on sulfur-deficient soils by lamb feeding tests. Alfalfa grown on the plots treated with sulfur was higher in crude protein, ether extract, and nitrogen free extract and lower in crude fiber. Also the digestibility of these constituents was greater for alfalfa produced on the sulfur treated areas. An attempt to improve the feeding value of the alfalfa produced on the untreated soil by the addition of methionine was unsuccessful.

Very comprehensive data have been obtained in a 10-year experiment in Michigan where corn, soybean, wheat, oats, and brome and timothy hay were grown on adjacent fertilized and unfertilized plots. These crops were fed to dairy cattle in an attempt to measure differences in nutritive value. The relatively small differences which occurred in the composition of all crops in any one year except timothy hay could not be attributed to fertilization (34). No significant differences were noted between treatments with regard to reproductive efficiency, health, heifer growth, and blood composition.

The milk production was slightly higher for Jersey cows on unfertilized feed, but this was reversed for Holstein cows (78). The cows secreted milk of practically uniform composition regardless of whether the feed came from fertilized or from unfertilized plots (35). Rats fed milk produced under the two treatments grew at the same rate (22).

Cooper (28) has suggested that bloat in ruminant animals consuming leguminous crops may be the result of phosphorus deficiency combined with a rich nitrogen or protein source. To date there is no experimental evidence to confirm his suggestion.

There are various reasons for the discrepancies which have been reported in the literature regarding the chemical composition of forages and their relative nutritive value when fed to livestock. Environmental factors vary greatly from one location to another (69). There may have been differences in the stages of maturity of forages studied by various workers. The effects of maturity on the chemical constituents of legume, legume-grass, and grass hays have been thoroughly surveyed by Van Riper and Smith (73). The results of their studies emphasize that consideration must be given to differences in maturity when conducting forage research.

Many legumes contain substances which, when consumed by the animal, produce effects on the reproductive system comparable to those induced by animal estrogens and synthetic compounds such as diethylstilbestrol (45, 46). An evaluation

of these substances in livestock production is impossible until more information is available on their levels in various forage species. However, it is quite probable they may be associated with some of the variability reported when animals were fed different forage mixtures. Morrison (56) mentions studies where the favorable effects on milk production and animal growth were associated with plant hormones in young actively growing pasture. At mature stages of plant growth these effects were not found. This author also states that some alfalfa and clover hays and some soybean oil meals have produced effects similar to those resulting from hormones.

Some of the variations which are reported in the literature regarding forage nutritive value may result from the method of feed preparation. Pelleting was found to be particularly advantageous for steers and lambs fed only forage (81). Animals fed pelleted alfalfa consumed more forage and made larger gains than animals fed chopped or long alfalfa. Meyer et al. (54) obtained similar results. Methods of curing and storing forage crops can markedly affect their nutritive value (69).

From the foregoing survey of the literature it is evident that in studies of the influence of fertilization on the nutritive value of crops the ultimate problem is evaluating the effects of many factors in a complex soil-plant-animal relationship. It is also evident that there is considerable uncertainty concerning the effects of varying levels of essential plant nutrients on forage quality.

Because of the world's food and nutrition problems, because forage crop production is basic to the agricultural industry of this province, and because fertilization of forage crops may affect both yield and quality of the crop produced, further work in this field may be justified.

The objectives of this study were to determine the effects of fertilization on production, chemical composition, and biological value of forage. The biological value was determined by feeding experiments with rabbits and sheep. In addition an artificial rumen technique measuring forage dry matter loss and volatile fatty acid production was also used to assess forage quality.

MATERIALS AND METHODS

A. Forage Fertilizer Trials

The trials were located on established stands of forage in three soil zones, namely Black, Thin Black, and Grey Wooded. The test areas consisted of long strip plots, each treatment being 8 feet wide and approximately 1,200 feet long. A special fertilizer applicator was designed to facilitate the application of the standard fertilizers used for the various treatments. The fertilizer applicator is shown in Figure 2. The equipment consisted of three standard 8-foot fertilizer attachments mounted on a 2-wheeled trailer. The attachments were driven independently by a V belt from one of the trailer wheels. This arrangement allowed simultaneous application of three separate fertilizer materials. The fertilizer treatments were broadcast in the spring as soon as it was possible to travel on the fields with a 1/2-ton truck and the trailer without damaging the experimental plots.

Table 1 contains the legal location, crop, soil zone, and treatments for the four field experiments considered in this study.

Yields were determined by weighing three square-yard samples cut from 10 locations in each treatment. The green weights were recorded in the field and representative samples were taken to the laboratory for moisture determination. This procedure allowed the yield data to be calculated in tons per acre of air-dry forage.

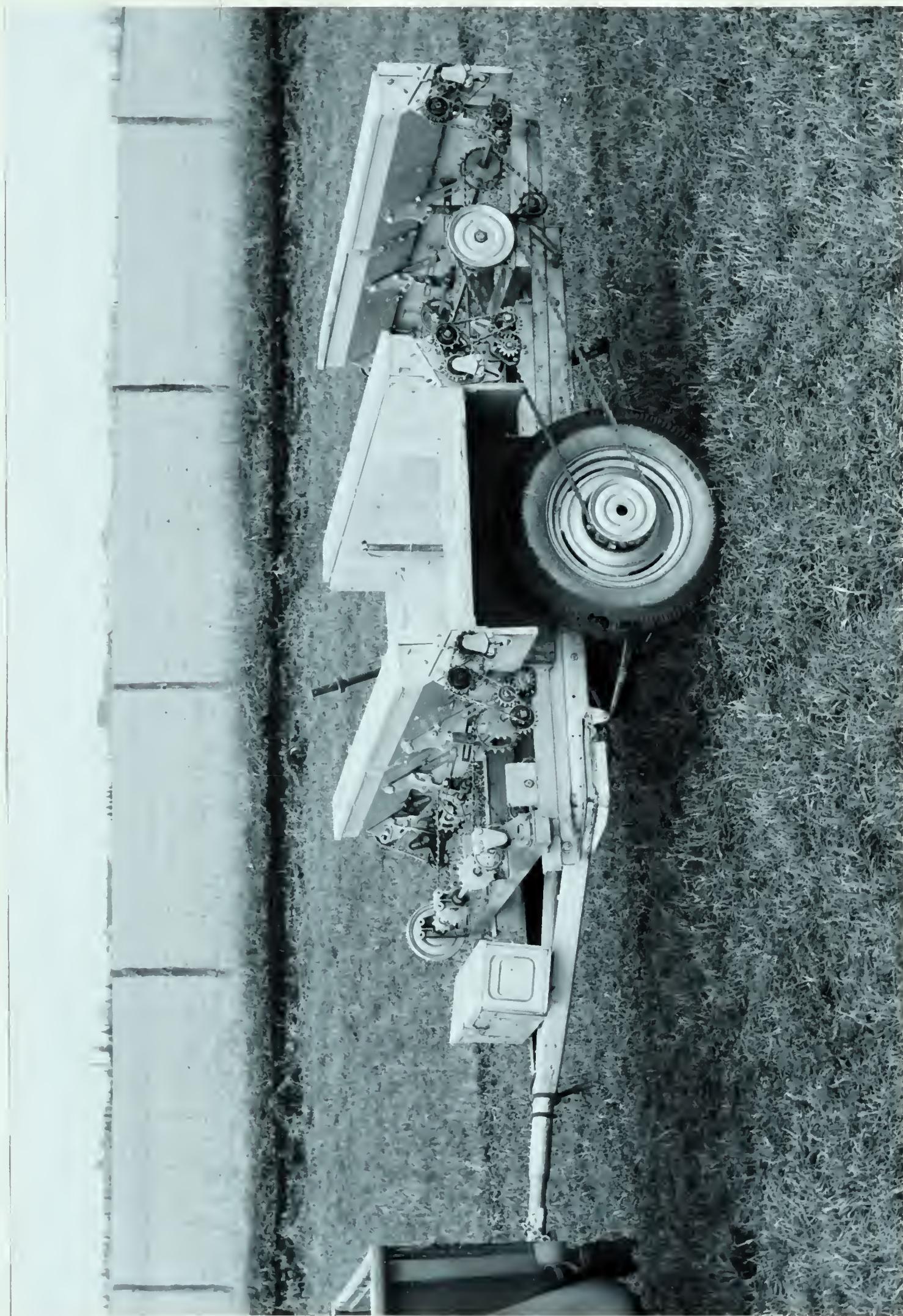


Figure 2. Ground-driven fertilizer applicator used for broadcast application of fertilizers to forage plots.

Table 1. Data concerning field fertilizer experiments.

Experiment No.	Treatment Designation	Nutrients Applied				
		N	P ₂ O ₅	K ₂ O	S	
pounds per acre						
<u>Experiment I (1957)</u>						
Farm: A. A. Pelletier	Check*	0	0	0	0	
Address: Pincher Creek	N20	20	0	0	0	
Legal Location:	N20 P30	20	30	0	0	
NE 6-7-29-14	N40*	40	0	0	0	
Crop: Brome grass	N40 P30*	40	30	0	0	
Soil Zone: Thin Black	N40 P60	40	60	0	0	
	N80 P30*	80	30	0	0	
	N80 P60	80	60	0	0	
<u>Experiment II (1956)</u>						
Farm: H. Byers	Check*	0	0	0	0	
Address: Clover Bar	N80 S20*	80	0	0	20	
Legal Location:	N80 P60 S20*	80	60	0	20	
NW 6-53-23-4	N80 P60 K40 S20*	80	60	40	20	
Crop: Brome grass						
Soil Zone: Black						
<u>Experiment III (1956)</u>						
Farm: Provincial Gaol	Check*	0	0	0	0	
Address: Fort	N30*	30				
Saskatchewan	N60*	60			anhydrous ammonia	
Legal Location:	N90*	90				
NW 29-54-22-4						
Crop: Brome grass	N20	20				
Soil Zone: Black	N40	40			ammonium sulfate	
<u>Experiment IV (1956)</u>						
Farm: E. Snell	Check*	0	0	0	0	
Address: Breton	N20 P30	20	30	0	0	
Legal Location:	N40 P30	40	30	0	0	
SW 33-47-3-5	N40 P60	40	60	0	0	
Crop: Alsike clover	N80 S20*	80	0	0	20	
Soil Zone: Grey Wooded	N80 P60 S20*	80	60	0	20	
(sulfur-deficient)	N80 P60 K40 S20*	80	60	40	20	
	N10 P60 S20*	10	60	0	20	

* Treatments used in feeding experiments.

The forage used in the feeding experiments was harvested in cooperation with the farmer using the farmer's equipment wherever possible. The forage was harvested at the stage of maturity recommended for good quality hay. Forage from the 1956 field experiments (Experiments II, III, and IV) was cured and baled in the field and trucked to the University Farm for storage. A week later the forage from Experiments II and III was found to be heating slightly, and at that time the bales were broken open and allowed to dry completely in a covered hay loft. The hay was then stored in large jute sacks. In the case of Experiment I, the forage was trucked to the University Soil Science Farm immediately after cutting and was dried at 140°F. with a forced air dryer. This drying procedure proved to be a very satisfactory method of obtaining high quality dried forage with little loss of leaves.

After thorough drying the forage samples were prepared for pelleting by grinding them in a hammer-mill using a 1/8-inch sieve. This was the recommended degree of fineness suggested by the United Grain Grower Feed Mill, Edmonton, Alberta, where the forage was pelleted. The pellets produced were approximately 1/4 inch in diameter and 1/2 inch long. Following pelleting, the feeds were stored in paper sacks in a dry room until required for feeding.

B. Plant Samples for Chemical Analysis

Botanically pure samples of the dominant species in the forages were collected in the field at the time of

harvesting. Care was taken to select plants of uniform maturity and growth throughout each treatment. These samples were taken directly to the laboratory where they were air dried and prepared for analysis by grinding in a Christy-Norris Laboratory Mill using a 1 mm. sieve. The prepared samples were then stored in glass jars prior to analysis.

Representative samples of the pelleted feeds were obtained by inserting a long 1-inch brass tube into the sacks of pelleted feed. This method of obtaining representative samples of pelleted feed was recommended by Gareau (37). The samples were then prepared and stored in the same manner as the botanically pure field samples.

C. Chemical Analysis

Pelleted feed samples and the botanically pure field samples were analysed for the following elements: nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, and sodium. Nitrogen determinations were made by the modified Kjeldahl method of Jackson (44) using mercury as the catalyst. Sodium bisulfite was dissolved in 40 per cent sodium hydroxide to precipitate the mercuric compounds. The ammonia was distilled into boric acid containing the mixed indicator brom cresol green and methyl red and was titrated with standard sulfuric acid.

Determinations for mineral components were made on the digests of 2 gm. plant material wet-ashed by a nitric-perchloric acid method, the reliability of which was thoroughly

studied by Gareau (37). The procedures for wet-ashing and determination of phosphorus, potassium, sulfur, calcium, magnesium, and sodium were the same as those outlined by Carson (21). Potassium was determined by a flame photometer method using a Beckman model DU. Phosphorus was determined by a spectrophotometric method where the vanadomolybdophosphoric yellow color was developed. Magnesium and calcium were determined titrmetrically with versene and sulfur was determined by precipitation with barium sulfate.

The crude fiber content of the pelleted feed samples was determined by a modified A.O.A.C. (7) method in which oven-dry feed samples were used instead of the residues from the ether-extract determination.

The gross energy of the pelleted feeds and the animal feces were determined using a Parr Oxygen Bomb Calorimeter according to a method described in the Parr Manual (6).

D. Methods of Biological Assays

(1) Rabbit Feeding Experiments

Albino rabbits from the colony maintained by the Department of Animal Science at the University of British Columbia were used in all the rabbit feeding experiments. Weanling rabbits, sibs, or cousin sibs of approximately 7 to 9 weeks of age were obtained. The feeding experiments were conducted during the winter months. Experimental

animals were shipped immediately prior to the experimental feeding period, and animals suffered considerably from the fluctuations in temperature during the long shipping period. In one particular shipment two animals were dead upon arrival at Edmonton. Some of the illness encountered during the feeding experiments may be partially attributed to their exposure during shipping.

Upon arrival at the University of Alberta, the experimental animals were housed in wire cages 24 inches by 16 inches by 14 inches which were designed for feces collection (Figure 3). These cages were located in the rabbit room of the Department of Animal Science. This room was air-conditioned with temperature, humidity, and light being controlled. During the course of the experiments the following conditions were maintained: temperature at 65° F., relative humidity at 40 to 45 per cent, and artificial light from 7:30 a.m. to 9:30 p.m. In one of the experiments lack of cages made it necessary to place two rabbits in each cage. This practise meant that feed consumption and feces output could not be determined for individual rabbits. One animal per cage was found to be most satisfactory even if the number of replicates per treatment were reduced.

All animals were fed a commercially prepared pelleted rabbit feed for the first seven days during which time weights were recorded daily. The animals were then allotted to groups according to litter, weight, and gain in

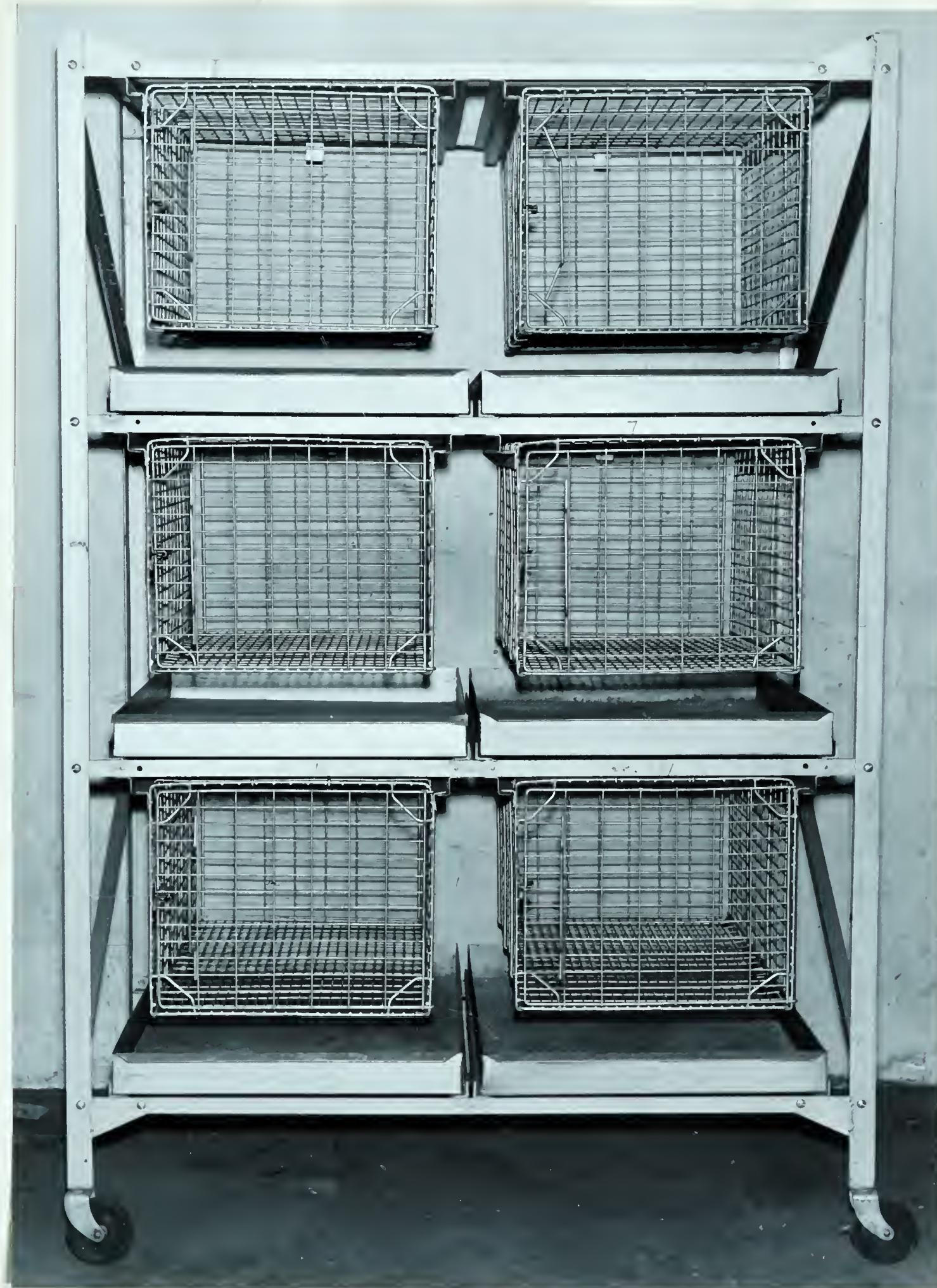


Figure 3. Wire cages designed for feces collection and used to house rabbits during feeding experiments.

weight during the preliminary period. Each group was then assigned at random to the experimental feeds to be assayed. The animals were immediately placed on a digestion experiment to evaluate the utilization of dry matter, protein, and energy. A 7-day adjustment period was followed by a 7 to 14-day test period. During the digestion experiment feed consumption was recorded, feces were collected, and animal weights were taken. The sole source of feed during this period was the experimental feed to which the animals had been allotted. Animals had access to iodized salt and water.

Because of the wide variability in animal weights from day to day, initial and final animal weights were obtained by averaging 3 daily weighings. Daily weights of feces were recorded for each cage. Representative feces samples from each cage were oven dried for moisture determination and then stored prior to analyses.

(2) Sheep Feeding Experiment

Four Suffolk shearling rams were used as experimental animals in the sheep feeding experiment. These animals were sheared and wormed prior to going on experiment. They were housed in individual pens in a closed barn. The sheep were allotted at random to one of four treatments from Experiment IV. Because of insufficient quantities of feed only one animal per treatment and only one set of experimental feeds was used. The sheep were fed the same feed for 17 days. After an adjustment period of 7 days, a digestion experiment was

conducted for 10 days during which time feed consumption was recorded and feces were collected. To permit the collection of feces each sheep was fitted with a canvas bag of the design suggested by Dr. F. Whiting, Canada Department of Agriculture, Experimental Farm, Lethbridge, Alberta. Digestibility of nitrogen, energy, and dry matter was determined for the 10-day digestion experiment.

(3) Artificial Rumen Experiment

Characteristics of different forages control the fermentation processes in the animal rumen through the amount and availability of the nutrients supplied to the rumen microflora. At best the fermentation in the minature artificial rumen represents an approximation of the fermentation process in the live animal's rumen. However, artificial rumen studies of forages do yield results which are closely related to the digestibility of dry matter, crude and digestible protein, and voluntary feed consumption (9, 30).

Minature artificial rumen studies were conducted on the five experimental feeds from Experiment IV. Dry matter loss and volatile fatty acid production in the artificial rumen were determined using a washed rumen inoculum (8).

RESULTS AND DISCUSSION

During the two years when field experiments were conducted for this project, considerable effort was expended in locating pure stands of forage and in collecting materials for feeding experiments from fields which gave striking yield responses to the application of fertilizers. Of the 17 experiments placed in the spring of 1956, 14 were sampled to determine yield. Hay for feeding experiments was obtained from only 3 of the 14 locations. In 1956 weather conditions during the hay growing season were very dry and unfavorable for maximum yield responses of forage crops to fertilizer application. Twenty-two field experiments were placed in 1957. Because of the extremely dry spring and early summer, only 10 of the experiments were sampled to determine yield. Feeding trial material was obtained from one experimental location.

A. Effect of Fertilization on Forage Yield

The yield data for the four field experiments from which feeding trial materials were obtained are presented in Table 2. The yield data for the other field experiments conducted in conjunction with this project may be found elsewhere (1, 2). It is evident from the check yields in Table 2 that forage growth was poor on these fields. This poor growth may have been due in part to the lack of moisture. However, the application of commercial fertilizers had marked effects on forage growth in all four experiments. Therefore,

Table 2. Effect of fertilization on the yield of dry forage for all treatments in Experiments I, II, III and IV.

Treatment Designation ⁽¹⁾	<u>Nutrients Applied</u>				Yield	L.S.D.
	N	P ₂ O ₅	K ₂ O	S		
pounds/acre				ton/acre		
<u>Experiment I (Brome grass)</u>						
Check*	0	0	0	0	0.3	
N20	20	0	0	0	0.7	
N20 P30	20	30	0	0	0.9	
N40*	40	0	0	0	1.1	
N40 P30*	40	30	0	0	1.2	
N40 P60	40	60	0	0	1.3	
N80 P30*	80	30	0	0	1.8	
N80 P60	80	60	0	0	1.6	0.3
<u>Experiment II (Brome grass)</u>						
Check*	0	0	0	0	0.5	
N80 S20*	80	0	0	20	1.2	
N80 P60 S20*	80	60	0	20	2.0	
N80 P60 K40 S20*	80	60	40	20	1.9	0.2
<u>Experiment III (Brome grass)</u>						
Check*	0	0	0	0	0.3	
N30*	30	0	0	0	1.0	
N60*	60	0	0	0	1.2	
N90*	90	0	0	0	1.3	
N20 S20	20	0	0	20	0.5	
N40 S40	40	0	0	40	0.8	0.2
<u>Experiment IV (Alsike clover)</u>						
Check*	0	0	0	0	0.2	
N20 P30	20	30	0	0	0.5	
N40 P30	40	30	0	0	0.8	
N40 P60	40	60	0	0	1.0	
N80 S20*	80	0	0	20	1.4	
N80 P60 S20*	80	60	0	20	1.5	
N80 P60 K40 S20*	80	60	40	20	1.6	
N10 P60 S20*	10	60	0	20	1.0	0.3

(1) In treatment identification P = P₂O₅; K = K₂O.

* Treatments used in feeding experiments.

the low yield on the check plots may have been the result of the fertility level of the soil.

In Experiment I forage yield increased significantly with increased rates of nitrogen application up to 80 pounds of nitrogen per acre. Increased phosphorus had a much lesser effect but tended to increase yield when combined with nitrogen.

In Experiment II the N80 S20 treatment significantly increased the forage yield. When 60 pounds of phosphate per acre were added in the N80 P60 S20 treatment, the yield was again increased. The addition of 40 pounds per acre of potash had little effect on forage yield.

The nitrogen in Experiment III was obtained from two nitrogen sources, anhydrous ammonia and ammonium sulfate. Significant yield responses were obtained with both forms of nitrogen. The greater response from the anhydrous ammonia may have been due to the dry season and the greater availability of this form of nitrogen. Anhydrous ammonia is placed directly in the soil, while the ammonium sulfate requires rainfall to wash it into the soil. Unpublished results from the Department of Soil Science indicate that under favorable conditions these two sources of nitrogen are of equal fertilizer value. Both nitrogen fertilizers produced substantial yield increases at low levels of nitrogen application. Little increase in yield resulted from the N90 treatment over the N60 treatment. Therefore, yield may have been limited at this point by another nutrient or some other growth factor such as moisture.

Experiment IV was located on a sulfur-deficient Grey Wooded soil. The yield of alsike clover was increased significantly by the fertilizer treatments. It is probable that the definite response of the legume to nitrogen was due to the sulfur deficiency which prevented adequate symbiotic nitrogen fixation. A combination of phosphorus and sulfur (N10 P60 S20) produced good yield response but even greater response was evident when those nutrients were combined with high rates of nitrogen. The complete treatment (N80 P60 K40 S20) was not appreciably better than the N80 S20 treatment. Thus, phosphorus and potassium were not important limiting nutrients in this field experiment.

The data of Table 2 clearly demonstrate that the yield of forage crops can be significantly increased by appropriate fertilization and that the fertilizer requirements vary with crops and soils.

B. Effect of Fertilization on Forage Chemical Composition

(1) Botanically Pure Field Forage Samples

The results of the chemical analyses of the botanically pure forage samples are recorded in Table 3. There are no data reported in Table 3 for botanically pure samples from Experiment I. Unfortunately, these samples were lost prior to analyses.

In Experiment II the N80 S20 treatment increased the content of nitrogen, phosphorus, calcium, magnesium, and sulfur but slightly depressed the level of potassium. The

Table 3. Effect of fertilization on the chemical composition of botanically pure forage samples.

Treatment Designation ⁽¹⁾	Per Cent Content*					
	N	P	K	Ca	Mg	S
<u>Experiment I (Brome grass)</u>						
Check						
N40						
N40 P30						
N80 P30						
Botanically pure samples for this experiment were unfortunately lost.						
<u>Experiment II (Brome grass)</u>						
Check	1.17	0.17	1.33	0.24	0.10	0.14
N80 S20	1.58	0.23	1.23	0.32	0.12	0.16
N80 P60 S20	1.56	0.21	1.16	0.30	0.13	0.17
N80 P60 K40 S20	1.74	0.22	1.22	0.33	0.14	0.19
<u>Experiment III (Brome grass)</u>						
Check	1.01	0.17	1.09	0.24	0.07	0.09
N30	1.00	0.17	1.17	0.26	0.10	0.08
N60	1.21	0.18	1.16	0.30	0.09	0.10
N90	1.41	0.18	1.25	0.33	0.11	0.12
<u>Experiment IV (Alsike clover)</u>						
Check	2.61	0.32	1.82	1.16	0.25	0.10
N80 S20	3.16	0.23	1.77	1.12	0.26	0.18
N80 P60 S20	3.58	0.36	3.27	1.62	0.35	0.25
N80 P60 K40 S20	3.36	0.34	3.38	1.65	0.34	0.25
N10 P60 S20	3.69	0.34	3.30	1.56	0.34	0.24

(1) In treatment identification P = P₂O₅; K = K₂O.

* All data on the oven dry basis.

same trend is evident in the N80 P60 S20 treatment. The application of potassium in the N80 P60 K40 S20 treatment had no effect on the potassium content but resulted in a further increase in the nitrogen content.

In Experiment III high amounts of nitrogen fertilizer resulted in increased levels of nitrogen, potassium, calcium, and magnesium in the forage. The N30 treatment had little effect on the chemical composition of the forage as compared to the check treatment. The phosphorus content of the forage was not affected by the various nitrogen treatments.

The chemical composition of the forage in Experiment IV varied greatly with fertilizer treatment. The N80 S20 treatment increased the nitrogen and sulfur content but depressed the phosphorus content of the forage. The N80 P60 S20, N80 P60 K40 S20, and N10 P60 S20 treatments increased the phosphorus content slightly and markedly increased the content of potassium, calcium, magnesium, and sulfur.

(2) Pelleted Forage Samples

Results for the chemical analyses of the pelleted forage samples are recorded in Table 4. The results from Experiment I show a general increase in nitrogen content with increasing nitrogen fertilization. The treatments had little effect on the content of the other elements. The phosphorus content of this forage is low for average brome grass. The fact that phosphorus fertilization did not increase either yield or phosphorus content of the forage may indicate that

Table 4. Effect of fertilization on the chemical composition of pelleted forage samples.

Treatment Designation ⁽¹⁾	Per Cent Content*					
	N	P	K	Ca	Mg	S
<u>Experiment I (Brome grass)</u>						
Check	1.22	0.10	1.67	0.31	0.14	---
N40	1.36	0.11	1.98	0.32	0.12	---
N40 P30	1.34	0.10	1.99	0.31	0.14	---
N80 P30	1.58	0.10	2.15	0.29	0.15	---
<u>Experiment II (Brome grass)</u>						
Check	1.53	0.17	1.57	0.21	0.07	0.07
N80 S20	2.06	0.19	2.34	0.42	0.16	0.19
N80 P60 S20	1.96	0.26	2.40	0.42	0.16	0.20
N80 P60 K40 S20	1.96	0.28	2.63	0.44	0.16	0.16
<u>Experiment III (Brome grass)</u>						
Check	1.14	0.18	1.36	0.47	0.09	0.13
N30	1.15	0.19	1.43	0.40	0.14	0.10
N60	1.23	0.17	1.49	0.41	0.18	0.11
N90	1.38	0.16	1.52	0.38	0.13	0.11
<u>Experiment IV (Alsike clover)</u>						
Check	2.28	0.37	2.24	1.12	0.28	0.14
N80 S20	3.28	0.38	2.84	1.43	0.31	0.23
N80 P60 S20	3.43	0.39	2.65	1.34	0.33	0.25
N80 P60 K40 S20	3.35	0.43	3.00	1.48	0.34	0.25
N10 P60 S20	3.30	0.40	2.86	1.43	0.33	0.27

(1) In treatment identification P = P₂O₅; K = K₂O.

* All data on the oven dry basis.

the fertilizer phosphorus was fixed near the soil surface and was not available for plant uptake.

The mineral content of the pelleted feed for Experiment II was considerably different from the mineral content of the botanically pure samples. This difference may have resulted from a small proportion of alfalfa in the forage mixture. Generally, the fertilizer treatments increased the content of all elements determined. More than 100 per cent increases resulted in the content of phosphorus, calcium, magnesium, and sulfur.

Increasing rates of nitrogen in Experiment III tended to increase the content of nitrogen, potassium, and magnesium, but seemed to depress the content of phosphorus, calcium, and sulfur in the forage. These results varied from the botanically pure samples where nitrogen treatments had little effect on the phosphorus content and tended to increase the calcium and sulfur content of the forage. This difference between samplings may suggest a maturity difference in the pelleted samples which was removed in sampling the botanically pure material.

The fertilizer treatments in Experiment IV resulted in a general increase in the content of all elements determined in the forage, but particularly in the content of nitrogen, potassium, calcium, and sulfur. The N80 S20 and N10 P60 S20 treatments appeared to have similar effects on the composition of the forage. The application of phosphorus in combination with a high level of nitrogen in the N80 P60 S20 treatment tended to increase the nitrogen content but lowered the content

of potassium and calcium slightly. When potassium was added to this treatment in the N80 P60 K40 S20 treatment, the reduction in potassium and calcium content disappeared and the content of phosphorus increased.

The seemingly large variations in some of the experiments between the chemical composition of the botanically pure forage samples and of the unsorted pelleted samples may be explained on the basis of differences in handling and sampling. As previously mentioned, considerable effort was expended to locate these experiments on pure stands of forage; therefore, botanically pure samples and the pellet samples should be very similar in plant composition. The chemical composition of the botanically pure field samples may have been affected by the manner in which they were handled following collection. Some samples had to be transported long distances before they could be dried and in some cases heating may have occurred. Also, maturity differences between treatments which were not eliminated in the pelleted materials may account for some difference in chemical composition. The differences between the data in Tables 3 and 4 demonstrate that it is extremely difficult to obtain representative samples of forage grown under field conditions. The data in Table 4 are likely to be more meaningful for feeding experiment comparison since the sampling technique has not omitted the differences which may have occurred in botanical composition or maturity of the forages.

C. Effect of Fertilization on the Biological Value of Forage

Animal feeding experiments were conducted using the experimental forages obtained from the four experiments discussed in the preceding sections. Each feed was fed ad libitum to the test experimental animals. The experiments are discussed individually.

(1) Rabbit Experiment I

Rabbit Experiment I was concerned with the forage treatments selected from field Experiment I. The data for this feeding experiment are recorded in Tables 5, 6, and 7.

Twenty-four rabbits were divided into 4 groups allotted at random to the 4 feeds. Following an adjustment period of 1 week the animals were maintained on experiment for a period of 4 weeks. During the early part of the experiment four of the rabbits died of what was suspected to be coccidiosis. One of these animals was fed the unfertilized forage and three were fed forage from the plot which received the N40 treatment.

The feeds from fertilized plots were superior to feed from the untreated plot as measured by average weight gains, feed consumption, feed utilization, and feed per gram gain (Table 5). Rabbits fed the N40 and N80 P30 feed showed significantly greater weight gains than the rabbits fed the unfertilized feed. The feed consumption per gram gain for the rabbits on the N80 P30 feed was significantly less than it was for rabbits on the check feed. Although

Table 5. Weight gain, feed consumption, feed per gram gain, and statistical analyses data for Rabbit Experiment I. (Animals on test for 28 days.)

Treatment Designation	No. Animals per Treatment	Ave. Initial Wt.	Ave. Final Wt.	Ave. Gain	Ave. Feed Cons.	Ave. Output	Ave. Feces	Ave. Feed Utilization	Ave. Feed/Gm. Gain
Check	5	1647	2129	482	4909	3281	1628	10.4	
N40 (a)	3	1779	2449	670	5830	3752	2078	8.8	
N40 P30 (b)	6	1764	2376	612	5375	3466	1909	8.9	
N80 P30 (b)	6	1755	2489	734	5511	3510	2001	7.7	

Analysis of Variance									
Source of Variation	Degrees of Freedom	Weight Gain	Feed Consumption	Feed/Gm. Gain	mean square				
Treatments	3	60,172*	60.67	6.838*					
Error and Replicates	16	12,430	24.31	1.468					
L. S. D. (a)					172.6				1.88
L. S. D. (b)					143.1				1.55

(a) (b) Signify the correct least significant difference to be used for comparing with check.
* Significant at the 5 per cent level.

no significant difference was found in the amount of feed consumed by rabbits on the various treatments, there was some indication of greater consumption of the fertilized forages.

Results of the analyses of feeds and feces are recorded in Table 6. Increases in the nitrogen content of

Table 6. Composition of feed and feces for Rabbit Experiment I.

Treatment Designation	Pellet Analysis			Average Feces Analysis		
	N	Crude Fiber	Cal./Gm.	N	Cal./Gm.	
	%	%	Cal.	%	Cal.	
Check	1.22	28.0	4.205	0.82	4.253	
N40	1.36	26.4	4.185	0.90	4.321	
N40 P30	1.34	27.0	4.104	0.90	4.321	
N80 P30	1.58	27.2	4.092	1.01	4.320	

the fertilized feeds were accompanied by decreases in the crude fiber and energy contents. The decrease in crude fiber content of fertilized forage is notable since increases are common, especially when phosphorus causes differences in maturity. Nitrogen and energy content of the feces were higher for the fertilized forage than they were for the unfertilized forage.

Digestibility data for Rabbit Experiment I are presented in Table 7. The differences in rabbit weight gain

Table 7. Digestibility data and statistical analysis for Rabbit Experiment I.

Treatment Designation	Digestion Coefficients			ADE / 1,000 Gm.Feed	ADE / 1,000 Gm.ADN	ADE / 1,000 Gm.ADN	Dig. Energy Cons.
	D.M.	N	Energy				
	%	%	%	Cal.	gm.	Cal.	gm.
Check	33.2	55.2	32.6	1370	6.7	204.2	33.0
N40 (a)	35.8	57.3	33.5	1403	7.8	180.3	45.5
N40 P30 (b)	35.6	56.6	32.2	1321	7.6	174.4	40.7
N80 P30 (b)	36.3	59.4	32.8	1340	9.4	143.0	51.6
							7389

Analysis of Variance

Source of Variation	Degrees of Freedom	Dig. D.M.	Dig. N	Dig. Energy	ADE / 1,000 Gm.Feed	ADE / 1,000 Gm.ADN	Dig. N Cons.	Dig. Energy Cons.
				mean square	mean square	mean square	mean square	mean square
Treatments	3	9.733**	16.90	1.200	5.414	6.857**	3.477**	333.9**
Error and Replicates	16	1.506	5.510	1.150	1.952	0.097	25.94	16.66
L.S.D. (a)		1.90			0.482	7.89	6.33	
L.S.D. (b)		1.58			0.400	6.53	5.24	

(a) (b) Signify the correct least significant difference to be used for comparing with check.
** Significant at the 1 per cent level.

and feed efficiency (Table 5) may be explained on the basis of differences in digestible dry matter and digestible nitrogen. The increased digestibility of dry matter for the fertilized forage was highly significant. The digestible nitrogen in the fertilized forage was not significantly different from that in the unfertilized forage. There were highly significant differences in favor of the fertilized feeds when calculations were made on the basis of apparent digestible nitrogen per 1,000 grams of feed. The greater consumption of digestible nitrogen for the fertilized forages was also highly significant. The feed energy was not significantly affected by the fertilizer treatments. However, the amount of digestible energy consumed tended to be higher for the fertilized forage because of greater feed consumption. Therefore, the increased growth rate of the rabbits fed the fertilized forage appears to be a result of increased feed consumption with improved digestibility of dry matter and nitrogen.

The average gains for the rabbits were not as great as may have been expected, probably because the forages which were fed barely met the recommended nutrient requirements for maintenance of rabbits (62).

The data from Rabbit Experiment I indicate that rabbits fed fertilized forage gained more weight and required less feed per gram gain than rabbits fed unfertilized forage. These differences in performance may be the result of greater dry matter digestibility for the fertilized forage as compared

to the unfertilized forage. Also, the higher nitrogen content of the fertilized forage combined with increased nitrogen digestibility and feed consumption resulted in much greater consumption of digestible nitrogen for the rabbits fed the fertilized forage.

(2) Rabbit Experiment II

The feed used in this trial was collected from field Experiment II. The results are recorded in Tables 8, 9, and 10.

As previously mentioned, the forage collected from field Experiment II was found to be heating approximately one week after it was baled and stored. The most severe heating occurred in the forages collected from the fertilized treatments. These forages had the highest moisture content when cut and apparently had not dried sufficiently when baled. When the heated bales were discovered, they were immediately broken open but heating had progressed far enough to materially affect the smell and feel of some of the forage.

The 20 rabbits used in Rabbit Experiment II were divided into 4 groups and allotted at random to the feeds to be studied. The rabbits were allowed 1 week to become adjusted to the feed. Then a digestion trial was conducted for 2 weeks during which time rabbit weight, feed consumption, and feces output were recorded. These data are reported in Table 8. The performance of rabbits fed the fertilized forages was inferior in all cases as compared to the performance of rabbits fed the check feed. The data for feed consumption indicated

Table 8. Weight gain, feed consumption, feed per gram gain, and statistical analysis data for Rabbit Experiment II. (Animals on test for 14 days.)

Treatment Designation	No. Animals per Treatment	Ave. Initial Wt.	Ave. Final Wt.	Ave. Gain	Ave. Feed Cons.	Ave. Feces Output	Ave. Feed Utilization	Ave. Feed/Gm. Gain
Check	5	1824	2152	328	2939	1794	1145	9.0
N80 S20	5	1870	2138	268	2624	1604	1020	9.8
N80 P60 S20	5	1783	2026	243	2606	1631	975	10.7
N80 P60 K40 S20	5	1759	2050	291	2692	1702	990	9.2

Analysis of Variance

Source of Variation	Degrees of Freedom	Weight Gain	Feed Consumption	Feed/Gm. Gain
Treatments	3	6,551	131,188	2.60
Error and Replicates	16	3,458	71,728	2.89

a definite palatability difference between the fertilized and unfertilized forage. This observation was substantiated by the results of a 5-day palatability experiment. Four rabbits were placed in a large cage (4 by 4 feet) and were offered the four forages in separate containers. Three hundred twenty grams of feed was placed in each container every day and the uneaten feed weighed back. The feeds were rearranged in a random manner daily. The average daily feed consumption for the four forages was: Check, 320 gm.; N80 S20, 235 gm.; N80 P60 S20, 49 gm.; and N80 P60 K40 S20, 21 gm. The check forage appeared to be the most acceptable feed to the rabbits.

Results of analyses of feeds and feces are recorded in Table 9. These data indicate a general increase in the

Table 9. Composition of feed and feces for Rabbit Experiment II.

Treatment Designation	Pellet Analysis			Average Feces Analysis		
	N	Crude Fiber	Cal./Gm.	N	Cal./Gm.	
	%	%	Cal.	%	Cal.	
Check	1.53	28.4	4.073	0.97	4.389	
N80 S20	2.06	29.5	4.152	1.14	4.384	
N80 P60 S20	1.96	30.6	4.142	1.06	4.343	
N80 P60 K40 S20	1.96	30.6	4.098	1.04	4.328	

nitrogen, crude fiber, and energy content of the feed as a result of fertilization. The fecal analysis showed a slight increase in the nitrogen content and a slight decrease in energy for the feces voided by the rabbits fed the forage from the fertilized plots.

Digestibility data for Rabbit Experiment II are recorded in Table 10. The performance of the rabbits in this experiment (Table 8) showed no relationship with the results obtained in Table 10. Although there tended to be a reduction in the digestibility of dry matter as a result of the fertilization, the percentage digested was satisfactory for a grass forage. The results for digestible nitrogen suggest an equal digestibility of nitrogen in all forages fed. However, the values for apparent digestible nitrogen per 1,000 gm. of feed and digestible nitrogen consumption show a highly significant difference in favor of the fertilized forage.

The results from Rabbit Experiment II indicate that rabbits fed fertilized forage made less gain in weight and consumed less feed than did rabbits fed unfertilized forage. Furthermore, fertilization apparently increased the nitrogen content and nitrogen digestibility of the forage. The poor performance of the rabbits on the fertilized forage may be explained on the following basis: (a) the nutritive value of the nitrogen in fertilized forage was considerably lower than that of the unfertilized forage, or (b) the reduced palatability, feed consumption, digestibility of dry matter

Table 10. Digestibility data and statistical analysis for Rabbit Experiment II.

Treatment Designation	Digestion Coefficients			ADE / 1,000 Gm.Feed	ADE / 1,000 Gm.Feed	ADE / Gm.ADN	ADE / Gm.ADN
	D.M.	N	Energy				
Check	39.0	61.3	34.2	1390	9.37	148.3	27.7
N80 S20	38.9	66.1	35.4	1472	13.6	108.2	35.1
N80 P60 S20	37.4	66.2	34.4	1424	13.0	109.5	33.7
N80 P60 K40 S20	36.8	66.4	33.2	1362	13.0	104.8	35.6

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Analysis of Variance

Source of Variation	Degrees of Freedom	Dig. D.M.	Dig. N	Dig. Energy	ADE / 1,000 Gm.Feed	ADE / Gm.ADN	ADE / Gm.ADN	Dig. N Cons.	Dig. Energy Cons.
Treatments	3	5.030	28.77	4.787	12,826	19.95**	2,287**	66.06**	205,400
Error and Replicates	16	2.244	10.67	4.604	7,119	0.284	36.94	8.794	164,500
L.S.D.						0.71	8.15	3.98	

** Significant at the 1 per cent level.

and energy consumption for the fertilized forage resulted in the lower gains. The latter possibility seems more reasonable since all these factors could well be associated with the heating which occurred during storage of this forage.

(3) Rabbit Experiment III

The forage used for this trial was selected from the treatments in field Experiment III. The results obtained in this feeding experiment are recorded in Tables 11, 12, and 13. These forages were found to be heating approximately a week after they had been baled and stored. Again the forage from the fertilized plots was most severely affected.

The 20 rabbits used in this experiment were divided into 4 groups and randomly allotted to the forages to be studied. The rabbits were placed on feed acclimatization 1 week prior to the digestion trial period of 2 weeks. The average weight gain, feed consumption, and grams feed per gram gain data for the digestion trial in Rabbit Experiment III are recorded in Table 11. One marked difference is indicated by these data. Rabbits fed the N60 forage made less average weight gain, consumed significantly less feed, and required more feed per gram gain than the rabbits fed any other forage. The same trend was evident for the rabbits fed the N90 forage but the differences were not significant.

A palatability experiment was conducted with the forages fed in this experiment following the same procedure used in Rabbit Experiment II. The average daily feed consumption

Table 11. Weight gain, feed consumption, feed per gram gain, and statistical analysis data for Rabbit Experiment III. (Animals on test for 14 days.)

Treatment Designation	No. Animals per Treatment	Ave. Initial Wt.	Ave. Final Wt.	Ave. Feed Cons.			Ave. Feces Output			Ave. Feed Utilization			Ave. Feed/Gm. Gain		
				gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	
Check	5	2191	2556	365	3974	2887	1087						10.9		
N30	5	2181	2549	368	4092	2937							11.1		
N60	5	2150	2446	296	3716	2676							12.6		
N90	5	2146	2478	332	3947	2800							11.9		

Analysis of Variance

Source of Variation	Degrees of Freedom	Feed Consumption		Weight Gain		Feed/Gm. Gain	
		mean square	mean square	mean square	mean square	mean square	mean square
Treatments	3		5,620		123,720*		5.567
Error and Replicates	16		5,960		25,050		6.332
L. S. D.							212.2

* Significant at the 5 per cent level.

for the four forages was: Check, 278 gm.; N30, 110 gm.; N60, 289 gm.; and N90, 150 gm. These data offered little assistance in explaining the results presented in Table 11.

The results of analyses of feed and feces for Rabbit Experiment III are recorded in Table 12. Increased

Table 12. Composition of feed and feces for Rabbit Experiment III.

Treatment Designation	Pellet Analysis			Average Feces Analysis		
	N	Crude Fiber	Cal./Gm.	N	Cal./Gm.	
	%	%	Cal.	%	Cal.	
Check	1.14	27.5	3.928	0.83	3.968	
N30	1.15	29.4	4.016	0.84	4.113	
N60	1.22	29.8	4.079	0.85	4.207	
N90	1.38	31.7	4.111	0.89	4.188	

nitrogen application was accompanied by increased crude fiber content of the forage. The N60 and N90 forage contained more of all constituents determined than did the forage from the check treatments.

The digestion data for Rabbit Experiment III are recorded in Table 13. Those data show significant differences in nitrogen digestibility and apparent digestible nitrogen per 1,000 gm. of feed between the forages from the N60 and N90 plots and the forage from the unfertilized plots. There was a highly significant difference in nitrogen consumption

Table 13. Digestibility data and statistical analysis for Rabbit Experiment III.

Treatment Designation	Digestion Coefficients			ADE / 1,000 Gm.Feed	ADE / 1,000 Gm.Feed	ADE / Gm.ADN	ADE / Gm.ADN	Dig. N Cons.	Dig. Energy Cons.
	D.M.	N	Energy						
	%	%	%	Cal.	gm.	Cal.	gm.	Cal.	gm.
Check	27.3	47.1	26.6	1046	5.37	194.8	21.3	4153	
N30	28.2	47.1	26.6	1070	5.37	199.2	22.1	4358	
N60	28.0	49.8	25.7	1048	6.08	172.4	22.5	3899	
N90	29.1	54.2	27.7	1138	7.49	151.9	29.5	4498	

Analysis of Variance

Source of Variation	Degrees of Freedom	Dig. D.M.	Dig. N	Dig. Energy	ADE / 1,000 Gm.Feed	ADE / 1,000 Gm.Feed	ADE / Gm.ADN	Dig. N Cons.	Dig. Energy Cons.
					mean square	mean square	mean square	mean square	mean square
Treatments	3	2.455	55.84**	3.200	9,877	4.892**	2,339**	72.79**	339,900
Error and Replicates	16	3.165	4.269	4.287	6,328	0.080	143.0	2.822	139,900
L.S.D.			2.77			0.38	16.0	2.35	

** Significant at the 1 per cent level.

for rabbits fed the forage from the N90 plots. No difference occurred between the N30 treatment and the unfertilized forage.

Generally, the results of Rabbit Experiment III suggest that the N30 treatment had little effect on the forage or rabbits fed the forage. The N60 and N90 treatments increased nitrogen digestibility and crude fiber content of the forage. The wide variability observed in the performance of the rabbits on the N60 forage appears to be associated with feed and energy consumption. The poor rabbit performance (Table 11) on the N60 and N90 treatments may have been associated with the heating which occurred in these forages after harvest.

(4) Rabbit Experiment IV-A

This feeding experiment was conducted using the alsike clover forage selected from field Experiment IV. The results are recorded in Tables 14, 15, and 16.

Shortly after the arrival of the rabbits for this experiment, a severe outbreak of what was suspected to be coccidiosis occurred. Four of the rabbits died leaving 23 of the original 27 animals for the feeding experiment. One week after the disease outbreak had been checked, the remaining 23 rabbits were divided into 5 groups and allotted to the feeds to be studied. The check feed was allotted to the group of five rabbits which had performed most satisfactorily from the time of arrival. Considering the importance of the results from the check feed, this procedure was followed to ensure adequate replication.

Because of a lack of cages during this feeding

experiment, 18 of the experimental rabbits were housed in 9 cages, or 2 rabbits to a cage. As a consequence, the data for these rabbits were reported as an average of two rabbits except for weight gain.

During the course of the acclimitization period on the respective feeds, the animals on the check feed performed very poorly as indicated by a consistent loss of weight and reduced feed consumption. This poor performance continued for a period of 10 days during which one of the rabbits on the check feed died. It was feared that 3 of the 4 remaining rabbits would also die if fed only the check feed. As a result these three rabbits were fed the N80 P60 K40 S20 feed. During the 10-day acclimitization period the rabbits fed the fertilized forage performed normally and were, therefore, maintained on experiment for an additional 10 days.

Fortunately, records of rabbit weight, feed consumption, and feces output were kept for the 10-day acclimitization period and these data were used as a basis for the results obtained in this experiment. The difficulties associated with this experiment complicated calculations and render interpretation difficult.

The results for weight gain, feed utilization data, and grams feed per gram gain for the 10-day acclimitization period in Rabbit Experiment IV-A are recorded in Table 14. The results presented clearly demonstrate the poor performance of the rabbits fed the unfertilized forage as compared with those fed fertilized forage. Weight gain, feed consumption,

Table 14. Weight gain, feed consumption, feed per gram gain, and statistical analysis data for Rabbit Experiment IV-A. (Animals on test for 10 days.)

Treatment Designation	No. Animals per Treatment	Ave. Initial Wt.	Ave. Final Wt.	Ave. Gain gm.	Ave. Feed Cons.	Ave. Feces Output gm.	Ave. Feed Utilization gm.	Ave. Feed/Gm. Gain gm.
Check	4	1754	1681	-73	925	448	477	----
N80 S20 (a)	5	1809	2143	334	1677	744	933	4.8
N80 P60 S20 (b)	4	1668	1989	321	1563	659	904	5.0
N80 P60 K40 S20 (b)	4	1724	2100	376	1585	636	949	4.1
N10 P60 S20 (c)	4	1579	1892	313	1361	558	803	4.4

Analysis of Variance

Source of Variation	Degrees of Freedom	Weight Gain	Degrees of Freedom	Feed Consumption	Feed Utilization
Treatments	4	172,680**	4	270,582*	115,852*
Error and Replicates	16	896.6	9	43,728	15,262
L.S.D. (a) (b) (c)				42.6 44.9 44.9	386 386 432

(a) (b) (c) Signify the correct least significant difference to be used for comparing with check.

* Significant at the 5 per cent level.

** Significant at the 1 per cent level.

and feed utilization were all significantly greater for the fertilized feed as compared to the check feed. Grams feed per gram gain could not be calculated for the rabbits on the check forage because of the negative average gain, but this value for the rabbits on the fertilized forage was very low.

A palatability experiment was conducted in the same manner as in Rabbit Experiments II and III. This experiment yielded the following results for average daily consumption of the five forages: Check, 340 gm.; N80 S20, 30 gm.; N80 P60 S20, 114 gm.; N80 P60 K40 S20, 12 gm.; and N10 P60 S20, 145 gm. From those results the check forage appeared to be highly acceptable to the rabbits and this fact made it difficult to understand the poor weight gain and feed consumption of the rabbits fed the check forage (Table 14).

Results of analyses performed on the feed used and feces recovered in Rabbit Experiment IV-A are recorded in Table 15. Those data indicate that the fertilized forage was

Table 15. Composition of feed and feces for Rabbit Experiment IV-A.

Treatment Designation	Pellet Analysis			Average Feces Analysis		
	N	Crude Fiber	Cal./ Gm.	N	Cal./ Gm.	
	%	%	Cal.	%	Cal.	
Check	2.28	22.9	3.878	2.00	4.345	
N80 S20	3.28	22.4	3.976	2.24	4.481	
N80 P60 S20	3.42	21.1	3.996	2.60	4.545	
N80 P60 K40 S20	3.34	22.0	3.913	2.33	4.548	
N10 P60 S20	3.30	20.6	4.072	2.52	4.528	

generally higher in nitrogen and energy content and lower in crude fiber content than was the check forage. The fertilized forage contained approximately 1 1/2 times as much nitrogen as the check forage. Nitrogen content of the feces from rabbits fed the fertilized forage was 1 1/5 times the nitrogen content of the feces from the check rabbits. The energy content of the feces produced on the check forage was lower than the energy content of the feces produced on the fertilized forage.

Average results calculated for the digestion phase of Rabbit Experiment IV-A are recorded in Table 16. A significant increase was found in the general digestibility of the fertilized forage over that of the check forage. This increase was highly significant for digestible nitrogen, apparent digestible energy, nitrogen per 1,000 gm. feed, and apparent digestible energy per gram of apparent digestible nitrogen. On the average, dry matter, nitrogen, and energy in fertilized forage was 6, 12, and 6 percentage units, respectively, more digestible than were these constituents in the check forage.

The differences between fertilized forages were small in comparison to the differences between fertilized and unfertilized forage in terms of rabbit performance and content of digestible nutrients. The N80 P60 K40 S20 forage appeared to be superior to the other fertilized forages. It was noted (Table 16) that in comparison to the N80 P60 K40 S20 forage, the N80 S20 forage contained considerably less digestible

Table 16. Digestibility data and statistical analysis for Rabbit Experiment IV-A.

Treatment Designation	Digestion Coefficients			ADE / 1,000 Gm. Feed		ADE / 1,000 Gm. ADN		ADE / 1,000 Gm. Feed		ADE / 1,000 Gm. ADN	
	D.M.	N	Energy	Gm. Feed	Cal.	gm.	Cal.	gm.	Cal.	gm.	Cal.
Check	51.9	57.8	46.1	1789	13.2	135.9	12.0	1641			
N80 S20 (a)	55.5	69.7	50.0	1986	22.8	86.9	38.3	3330			
N80 P60 S20 (a)	57.9	68.0	52.1	2081	23.2	89.7	36.2	3248			
N80 P60 K40 S20 (a)	59.8	72.0	53.3	2085	24.0	86.7	38.1	3308			
N10 P60 S20 (b)	59.0	68.7	54.4	2214	22.6	97.7	30.8	3016			

Analysis of Variance

Source of Variation	Degrees of Freedom	Dig. D.M.	Dig. N	Dig. Energy	Dig. / 1,000 Gm. Feed	Dig. / 1,000 Gm. ADN	Dig. N Cons.	Dig. Energy Cons.
		mean square	mean square	mean square	mean square	mean square	mean square	mean square
Treatments	4	29.09*	90.01**	29.15*	66,643**	60,018**	1,306**	369.0**
Error and Replicates	9	5.798	10.25	5.103	7,435	0.788	11.05	16.00
L.S.D. (a)		4.45	5.91	4.17	159	1.64	6.14	7.39
L.S.D. (b)		4.97	6.61	4.66	178	1.83	6.86	8.26

(a) (b) Signify the correct least significant difference to be used for comparing with check.

* Significant at the 5 per cent level.

** Significant at the 1 per cent level.

dry matter and energy and slightly less digestible nitrogen; the N80 P60 S20 forage had slightly less digestible dry matter and energy and considerably less digestible nitrogen; the N10 P60 S20 forage was equivalent in digestible dry matter and higher in energy but had less digestible nitrogen. Those data suggest the possibility that the high nitrogen application to this forage resulted in a nutrient imbalance which was partially corrected by application of phosphorus and completely corrected with the addition of phosphorus and potassium.

The results from Rabbit Experiment IV-A indicate that the forage from the fertilized treatments was superior to forage from the unfertilized treatment. Rabbit performance in terms of weight gain and digestibility of nutrients was significantly increased by the feeding of fertilized forage. The difference in the results obtained may be explained on the basis of low feed consumption and poor digestibility of the check forage. However, these factors did not seem sufficiently poor to justify the very poor performance of the rabbits fed the check forage, especially when the acceptability of the check forage in the palatability experiment is considered. It is possible that some nutritive factor not determined in this experiment was present in the fertilized forage and not in the unfertilized forage. In the palatability experiment, where the rabbits had access to fertilized and unfertilized forage, the unfertilized forage was acceptable, but in combination with the fertilized forage.

(5) Sheep Experiment IV-B

This was a feeding experiment using shearling rams as the test animals and employing some of the forages from field Experiment IV. The N10 P60 S20 forage used in Rabbit Experiment IV-A was omitted because of insufficient quantity of forage from this treatment. The results are recorded in Tables 17 and 18.

The 4 sheep were allotted at random to the 4 forages to be studied. After a preliminary feeding period of 7 days, a digestion trial was conducted for 10 days during which time feed consumption and feces output were recorded (Table 17). Little attention was given to the results for weight gain, because the length of time on test was short and initial and final weights of the animals were determined by a single weighing in each case. The sheep fed the check forage consumed considerably less than the sheep fed the fertilized forage. However, this difference may have been associated with the lighter weight of the sheep on the check forage. The sheep on the N80 S20 forage consumed slightly more feed than the sheep on the other two fertilized forages.

Results of analyses of the feed and feces and the results calculated from digestion trial are recorded in Table 18. The feed analyses were the same as those reported for Rabbit Experiment IV-A where the fertilized forage was generally high in nitrogen and energy content and low in crude fiber content. Sheep fecal nitrogen was higher than rabbit fecal nitrogen for the check, N80 S20, and N80 P60 K40 S20 forages.

Table 17. Weight gain, feed consumption, and feed utilization for Sheep Experiment IV-B.

Treatment Designation	No. Animals per Treatment	Initial Wt.	Final Wt.	Gain	Feed Consumption		Feed Utilization	
					1b.	1b.	gm.	gm.
Check	1	165	159	-6	22,350	10,440	11,910	
N80 S20	1	203	208	5	34,680	13,620	21,060	
N80 P60 S20	1	190	200	10	30,880	12,660	18,220	
N80 P60 K40 S20	1	194	194	0	30,880	11,380	19,500	

Table 18. Composition of feed and feces digestion coefficients and apparent digestible energy and apparent digestible nitrogen data for Sheep Experiment IV-B.

Treatment Designation	Pellet Analysis			Feces Analysis		
	N	Crude Fiber	Cal./ Gm.	N	Cal./ Gm.	Cal.
		%	%		%	
Check	2.28	22.9	3.878	2.24	4.201	
N80 S20	3.28	22.4	3.976	2.48	4.228	
N80 P60 S20	3.42	21.1	3.996	2.53	4.273	
N80 P60 K40 S20	3.34	22.0	3.913	2.50	4.225	
65 -						
Digestibility Data						
Treatment Designation	No. Animals per Treatment		Digestion Coefficients		ADE / 1,000 Gm.Feed	
	D.M.	N	Energy	Gm.Feed	1,000 Gm.Feed	ADE / Gm.ADN
	%	%	%	Cal.	gm.	Cal.
Check	1	53.3	54.1	49.4	1918	12.3
N80 S20	1	60.7	70.3	58.2	2319	23.1
N80 P60 S20	1	59.0	69.7	56.2	2249	23.8
N80 P60 K40 S20	1	63.1	72.4	60.2	2355	24.2
						97.3

However, there was the same trend for increased nitrogen in the feces voided by the sheep fed fertilized forage. Energy content of the sheep feces was lower than for the rabbits' feces. There was little difference in energy content of the sheep feces from the fertilized and unfertilized forages.

Results for the sheep feeding experiment are remarkably similar to those for the rabbit feeding experiment which involved the same feeds. Fertilized forage contained considerably more digestible dry matter, nitrogen, and energy than did the check forage. The ratios of energy to nitrogen was again considerably higher for the check forage than for the forages from fertilized plots. Forage from the N80 P60 K40 S20 treatment appeared to be superior in digestibility of dry matter, nitrogen, and energy to the other two fertilized forages. This same trend was observed in Rabbit Experiment IV-A. Generally, the sheep digested dry matter and energy more efficiently than did rabbits but there was little difference in the efficiency of nitrogen digestibility between the two animals.

The results of Sheep Experiment IV-B are obviously of limited value because of the shortness of the experiment and there being only one animal on each feed. However, the data from this experiment do corroborate the results obtained in Rabbit Experiment IV-A, but they do not explain or clarify the poor performance of the rabbits fed the unfertilized forage in Rabbit Experiment IV-A.

(6) Miniature Artificial Rumen Experiment IV-C

In this experiment dry matter loss and volatile fatty acid production in the artificial rumen were determined on the forages selected from field Experiment IV using a washed rumen inoculum. These same forages were studied in Rabbit Experiment IV-A and Sheep Experiment IV-B.

The results for Artificial Rumen Experiment IV-C are recorded in Table 19. Marked differences existed in the

Table 19. Artificial rumen results for forages used in Rabbit Experiment IV-A and Sheep Experiment IV-B.

Treatment Designation	Dry Matter Loss		Fatty Acid Production	
	24 Hr.	48 Hr.	24 Hr.	48 Hr.
	%	%	mgm.(1)	mgm.(1)
Check	36.9	47.8	60.4	93.6
N80 S20	42.2	58.4	73.4	120.3
N80 P60 S20	44.1	63.4	73.5	132.8
N80 P60 K40 S20	44.8	59.8	75.2	118.3
N10 P60 S20	44.6	56.5	83.0	124.9

(1) Mgm. fatty acid per 500 mgm. forage.

proportions of dry matter loss and the amounts of fatty acid produced from fertilized and unfertilized forage. A close parallel exists between the results obtained by the artificial rumen technique and the digestibility of dry matter and nitrogen determined in the two animal experiments.

Despite the limitations mentioned before in the two animal experiments and those known to exist in the artificial rumen technique, all three experiments show the same trends when results for the fertilized and unfertilized forages are compared. On the basis that the results of each experiment support those of the others, it seemed reasonable to assume that fertilization improved the nutritive value of this forage and that small differences may have existed in nutritive value between the forages receiving different fertilizer treatments.

D. General Discussion of Results

Rabbits were used in preference to large farm animals for the main part of this study as a matter of economy. However, rabbits are herbivorous mammals and they have, therefore, dietary requirements that are similar to some farm animals. Crampton *et al.* (29) and Hawkins (40) have demonstrated a consistent relationship between the digestibility of protein by rabbits and steers. Matrone *et al.* (53) found that rabbits and sheep responded differently to variations in forage quality; but, they suggested that rabbits may be better experimental animals than ruminants for experimentation seeking to find differences in nutritive value of forages resulting from fertilizer practices because the rabbit is more sensitive to variations in the nutritive value of forages. Studies on the efficiency of forage utilization by rabbits may also be of value in their own right as demonstrated by Bradefield and Maynard (15). They found that rabbits compared favorably

with the chicken as an efficient producer of meat as measured by protein and calorie efficiency, feed efficiency, and percentage edible portion of the carcass. Thus, the rabbit itself may have possibilities as a domestic meat animal.

The data concerning digestible energy content of the forages used in these experiments warrants further discussion. It was noted that the digestible energy content was relatively low for all forages as determined by both rabbit and sheep digestion experiments. To compare the values obtained with those of standard data for forage digestibility, it was necessary to convert the digestible energy data to total digestible nutrients (T.D.N.). This was done using the formula recommended by Swift (70): 2,000 Calories of digestible energy are equivalent to 1 pound of T.D.N. The results of these calculations are recorded in Table 20 which also lists the average analyses for T.D.N. on brome grass and alsike clover as given by Morrison (56).

Table 20. Total digestible nutrients calculated for forages used in animal feeding experiments I to IV-B and standard T.D.N. values for brome grass and alsike clover.

Treatment	Experiment Numbers (1)					Standard T.D.N. Values (2)	
	Brome Grass			Alsike Clover		Brome	Alsike
	I %	II %	III %	IV-A %	IV-B %	%	%
Check	31.1	31.5	23.7	40.6	43.5	49.3	53.2
Fertilized	30.7	32.2	24.6	47.4	52.3		

(1) T.D.N. was calculated from digestible energy using 2,000 Cal. = 1 lb. T.D.N.

(2) Average T.D.N. from Morrison (56).

As shown in Table 20, per cent T.D.N. as determined by rabbit digestion was considerably lower for both brome grass and alsike clover than the standard values. This difference was not as great for the fertilized alsike clover as for the fertilized brome grass. Little difference was found between sheep digestibility of nutrients (IV-B) on the fertilized forage and the standard values. Although rabbits digest forage less efficiently than sheep, the results for Rabbit Experiments I to III are strikingly below Morrison's (56) standard values. It is probable that advanced maturity of the brome grass forage or some other factor contributed to the very low digestibilities in Rabbit Experiments I to III.

Swift (70) has stated that the energy requirement of animals for maintenance exceeds the requirement for all other purposes. He states that if this requirement is satisfied, it is likely that all other dietary requirements will be satisfied incidentally. Crampton (30) has reported that differences in nutritive value of forages are clearly reflected in the level of voluntary intake. The energy intake of the animal is dependent on the quantity of forage consumed and the digestible energy content of that forage. The data reported in this study show that there was little difference in the digestible energy content of the fertilized and unfertilized brome grasses studied. However, rabbits fed fertilized brome grass consumed more feed than those fed the unfertilized forage. This increased consumption resulted in a marked increase in energy consumption by rabbits fed fertilized forages. The data for

alsike clover forage show that digestible energy in the forage and feed consumption were significantly increased by soil fertilization. Thus, digestible energy consumption was also significantly improved by the fertilizer treatments. If useful energy is normally the primary limiting factor determining the nutritive value of forages, then digestible energy becomes a measure of differences in feeding value between forages. On this basis the nutritive value of the forage produced on fertilized soil was greatly improved. This reasoning may be applied to protein digestibility and consumption.

Probably the superiority of fertilized forages reported in this study was the result of more rapid digestion which enabled more rapid passage of the feed through the digestive tract. Reasons for these differences are not revealed by the data reported. However, Crampton (30) has suggested that there is a relationship between microflora nutrition and the lignification of cellulose in forages. Perhaps fertilization affected such lignification. In any case, it is clear that the differences in intake between the forages grown on fertilized and unfertilized soil was a factor of considerable importance in the studies reported herein.

SUMMARY AND CONCLUSIONS

Results obtained from the field forage tests demonstrate that yield of forage can be substantially increased by the use of fertilizers. Nitrogen fertilization resulted in the most consistent forage yield increase. However, the application of phosphorus in combination with nitrogen increased forage yields in some cases.

The effect of fertilizer application on the mineral composition of forages varied greatly between experiments. The most frequent and consistent effect was an increase in the nitrogen content of fertilized forage as compared to unfertilized forage. Differences in forage quality were not distinguished by the chemical analysis performed in this study. However, nitrogen determinations may be of considerable value when other quality factors are known or fixed.

The nutritive value of forages as measured by animal feeding experiments may be improved by the application of fertilizers. Harvesting at the proper stage of maturity and storage at the proper moisture content may be more critical for fertilized forage than for unfertilized forage. Data from the animal experiments indicated that increased dry matter and nitrogen digestibility, and greater feed consumption were the factors associated with the higher nutritive value of the fertilized forage as compared to the unfertilized forage.

On the basis of these experiments rabbits digested forage energy less efficiently than sheep but appeared to

digest forage nitrogen as efficiently as sheep. The rabbits were very sensitive to changes in the nutritive value of forage and required small quantities of forage for feeding purposes. They were therefore very satisfactory pilot animals for forage comparison. Moreover, the rabbit may be very useful in studies which may involve physiological changes in animals as affected by forage quality.

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